Validation of CERES-MODIS Cloud Properties over Arctic Using ARM and CloudSat/CALIPSO Observations

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Goals of this study

1) To compare CERES-MODIS cloud fraction with CloudSat/CALIPSO results over entire Arctic during 2006-2008.

2) To compare CERES-MODIS cloud properties with ARM and CloudSat/CALIPSO results at ARM NSA site:

➔Cloud fraction

➔ Cloud-base and -top heights

➔ Daytime cloud microphysical properties from the selected single-layered stratus cases

- **DOE ARM NSA Surface observations/ retrievals**
  - Cloud fraction➔ derived from radar-lidar observations
  - Cloud-base and -top heights➔ derived from radar-lidar
  - Liquid water path➔ retrieved from microwave radiometer
  - Daytime single-layered stratus cloud effective radius r_e and optical depth ➔ retrieved from a modified Delta-2 stream radiative transfer model (Dong and Mace 2003).
  - Results are averaged over 3 hours centered at the time of the satellite overpass

- **CloudSat/CALIPSO Satellite observations/retrievals**
  - Cloud-base and -top heights from Level 2B data products, determined by both 94 GHz radar and LIDAR
  - Vertical resolution of 240 m
  - To increase the samples, results were averaged into 3^0x3^0 grid box over ARM NSA

CERES-MODIS Cloud Properties

- **Daytime: Retrievals from CERES Edition 2 Visible Infrared Shortwave-infrared Split-window Technique (VISST, using 0.65-um to retrieved optical depth) over snow-free surfaces and the Shortwave-infrared Infrared Near-infrared Technique (SINT, using 1.62-um for TERRA and 2.13-um for Aqua) over snow/ice covered surfaces.**
- **Night-time, retrievals are from the Shortwave-infrared Split-window Technique (SIST).**
- **Results averaged into 1^0x1^0 grid box over ARM NSA site**

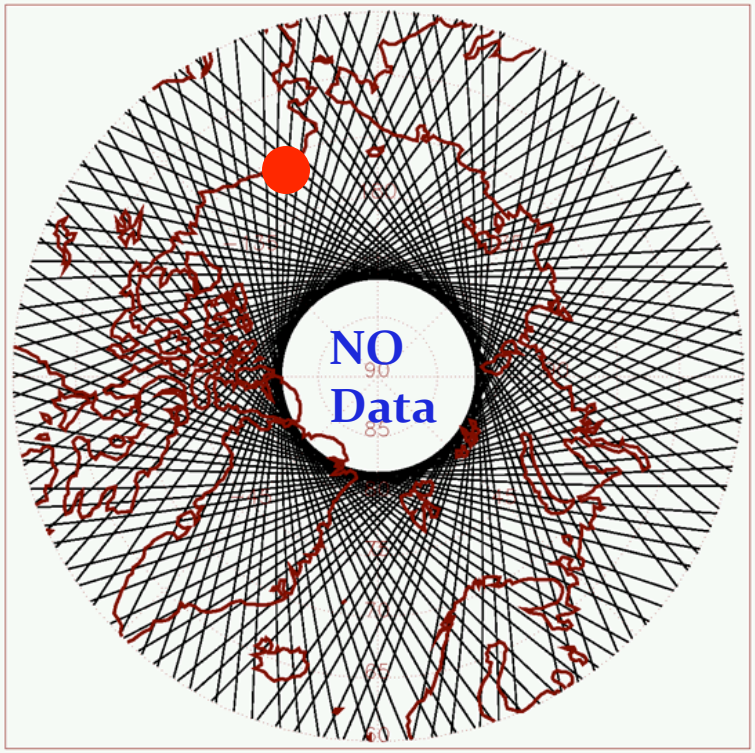
Temporal, Spatial, and Spatio-Temporal Continuity

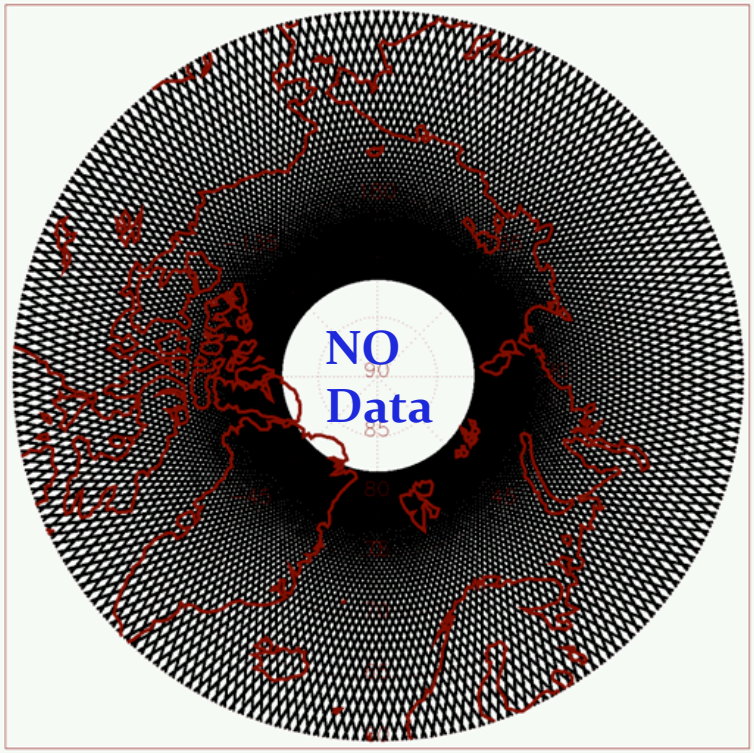
- **Temporal continuity (but point observations)**
  - **Example: DOE ARM surface measurements**
- **Spatial continuity**
  - **Most Polar orbiting satellites, such as Terra and Aqua**
- **Spatio-temporal continuity**
  - **Geostationary satellites, such as GOES**
- **Non spatio-temporal continuity (pencil beam)**
  - **CloudSat/CALIPSO measurements (not enough samples)**

1) To compare CERES-MODIS cloud fraction with CloudSat/CALIPSO results over entire Arctic during 2006-2008

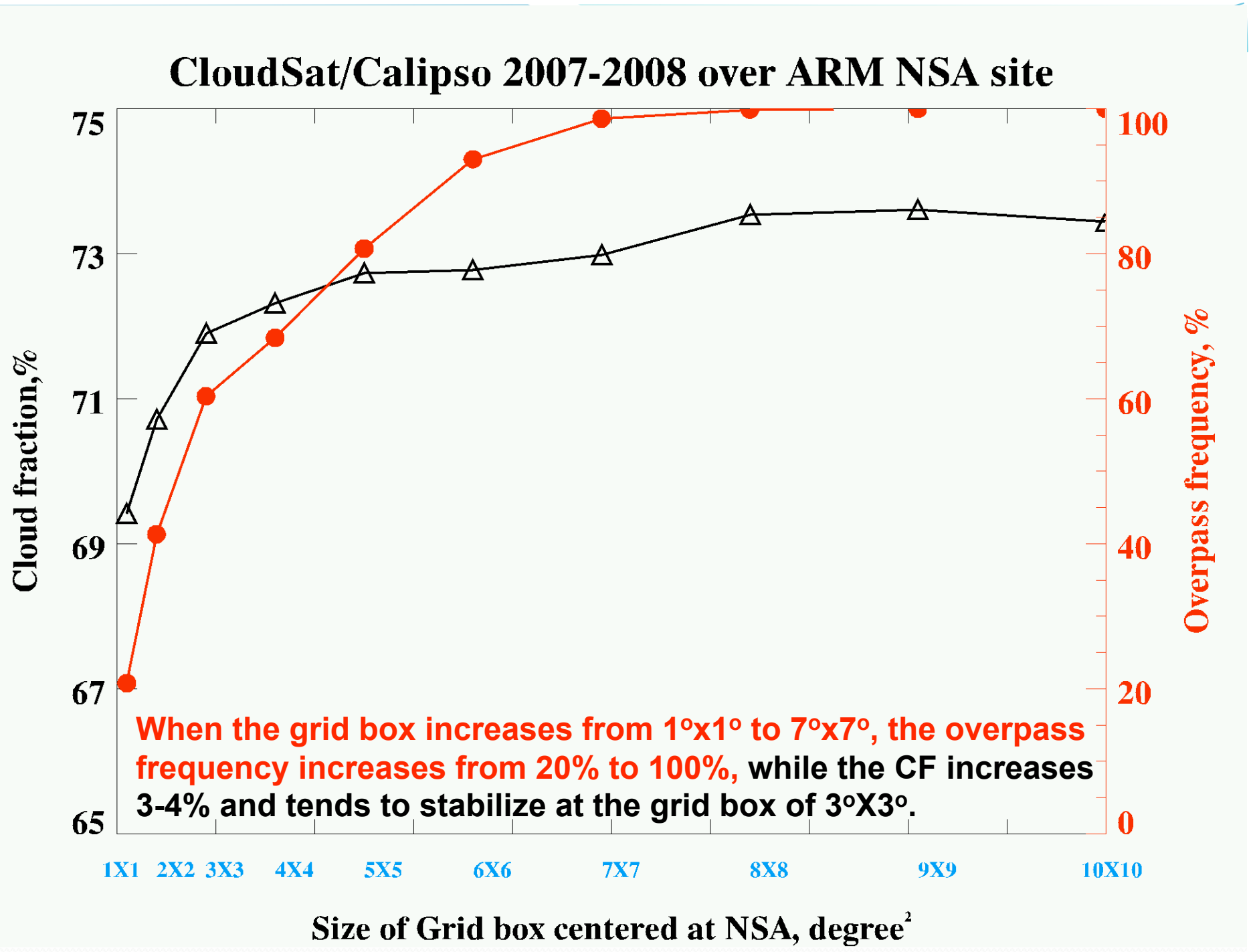
CloudSat overpasses over latitudes ≥ 60°N

~ 400 overpasses/month 2 years (10,000 overpasses)





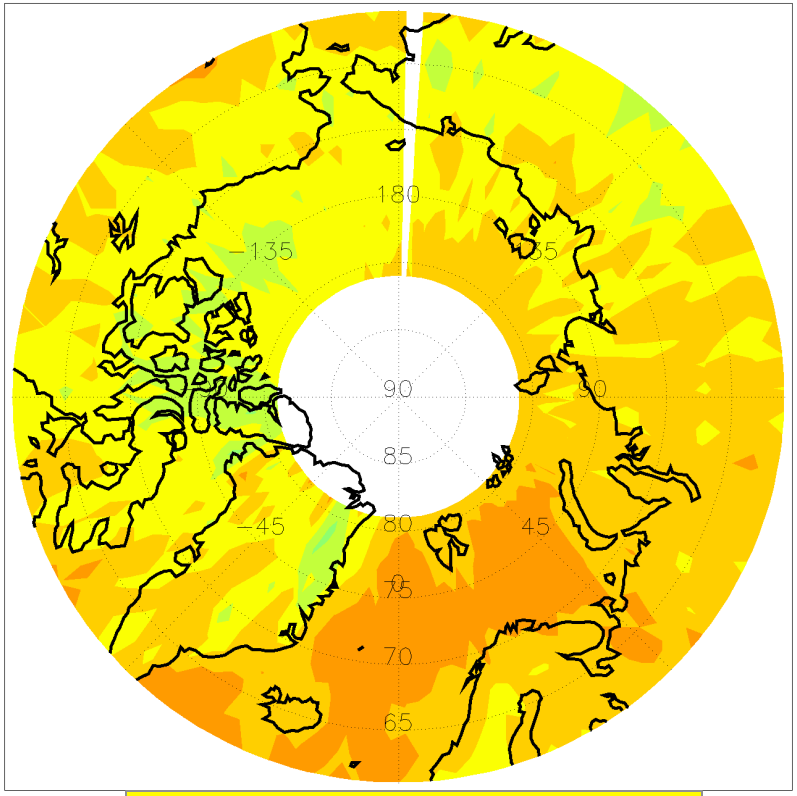
- As latitude increases towards the North Pole, CloudSat sampling increases.
- At lower latitudes, sampling is less frequent and some areas remain untouched by the overpass, leading to sampling issues when averaging over grid boxes.


CloudSat/Calipso 2007-2008 over ARM NSA site
Cloud fraction,%
75
73
71
69
67
65
Overpass frequency, %
100
80
60
40
20
0
When the grid box increases from 1°x1° to 7°x7°, the overpass frequency increases from 20% to 100%, while the CF increases 3-4% and tends to stabilize at the grid box of 3°X3°.
1X1
2X2
3X3
4X4
5X5
6X6
7X7
8X8
9X9
10X10
Size of Grid box centered at NSA, degree²

CloudSat/CALIPSO

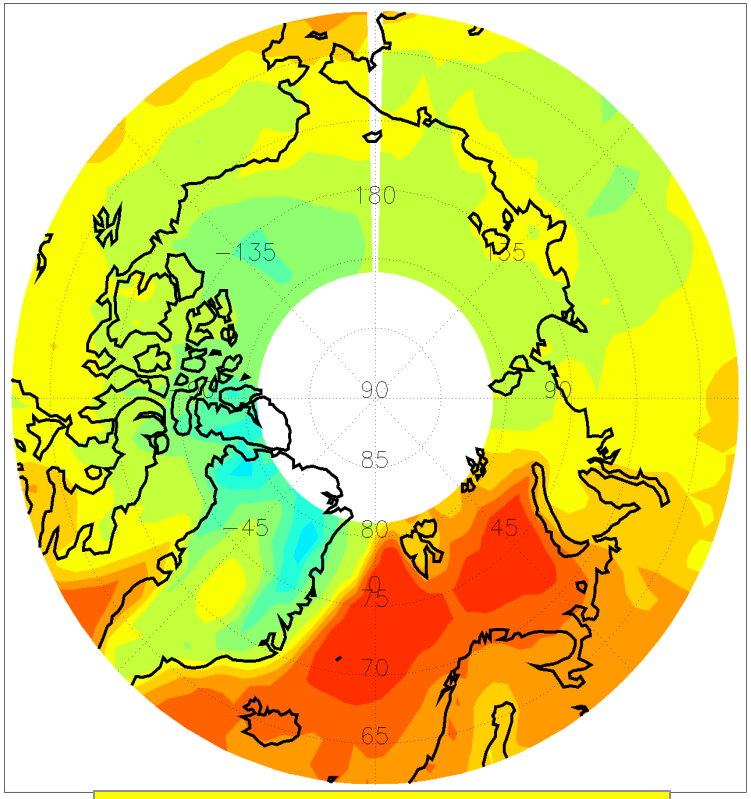
CERES-MODIS

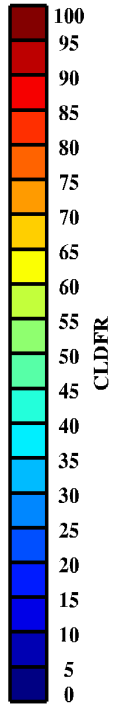
CloudSat/CALIPSO Cloud Fraction for 200607-2008



Mean CF = 65.3%

MODIS Cloud Fraction for 200607-200812



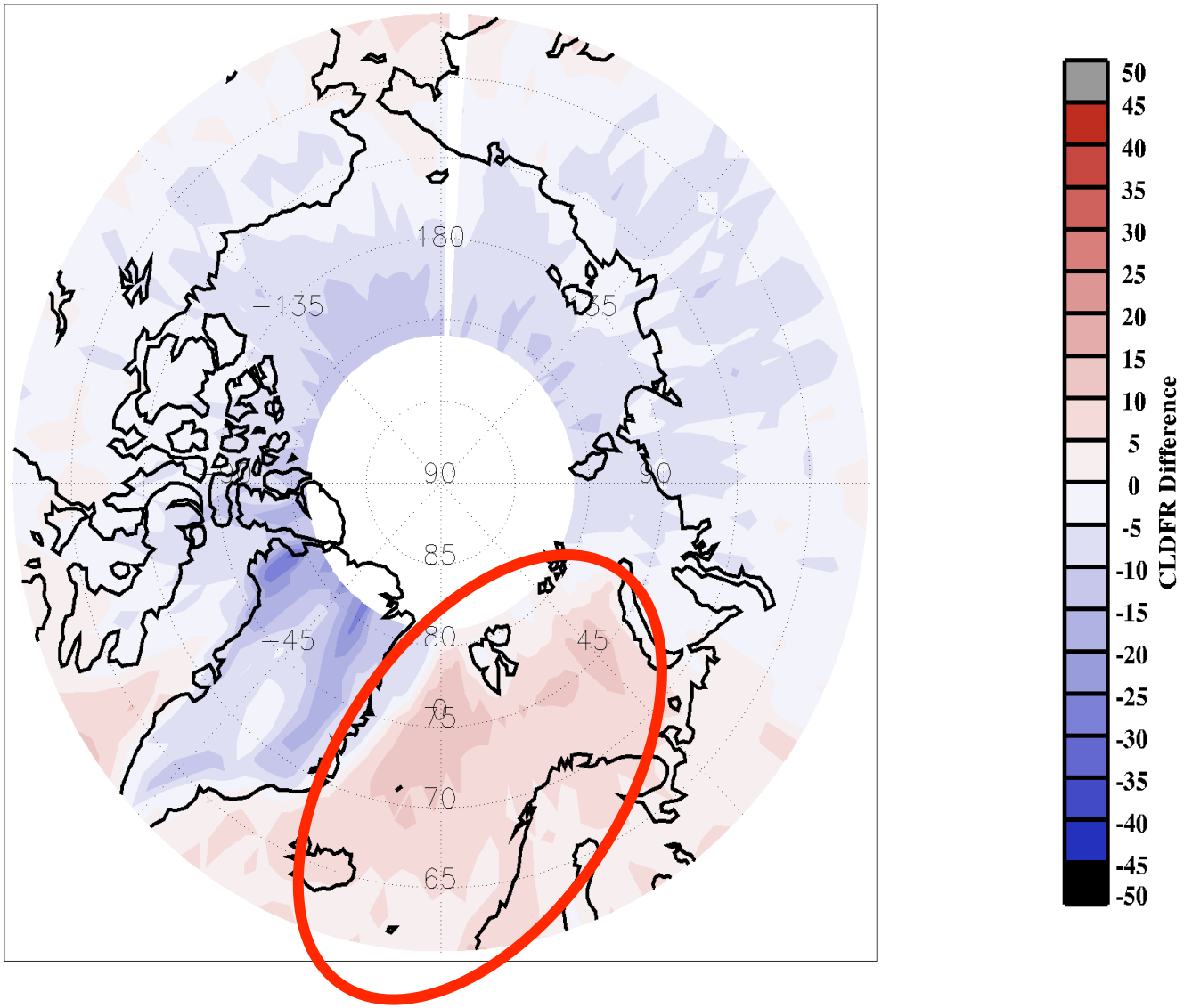


Mean CF = 63.4%

➔Some general features are similar (e.g. higher cloud fractions over east of Greenland, and some lower cloud fractions on the east coast of Greenland).

➔Although their mean CF difference is only 2%, there are large differences over some regions, possible due to active and passive remote sensing methods to detect clouds over snow/ice covered surfaces.

MODIS-CloudSat Cloud Fraction Difference



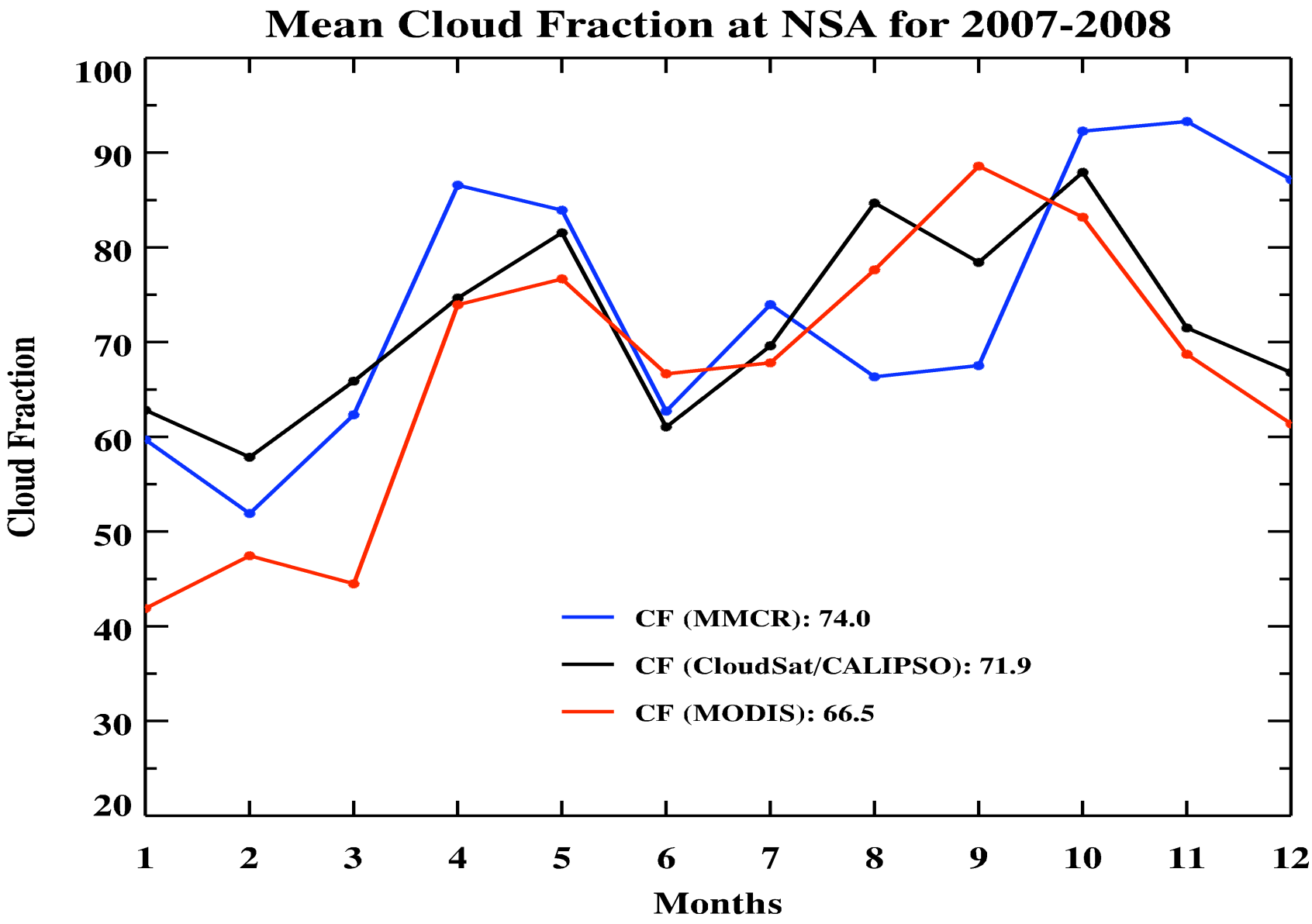
Conclusion: MODIS underestimated CFs over entire Arctic region except for east of Greenland

2) To compare CERES-MODIS cloud properties with ARM and CloudSat/CALIPSO results at ARM NSA site:

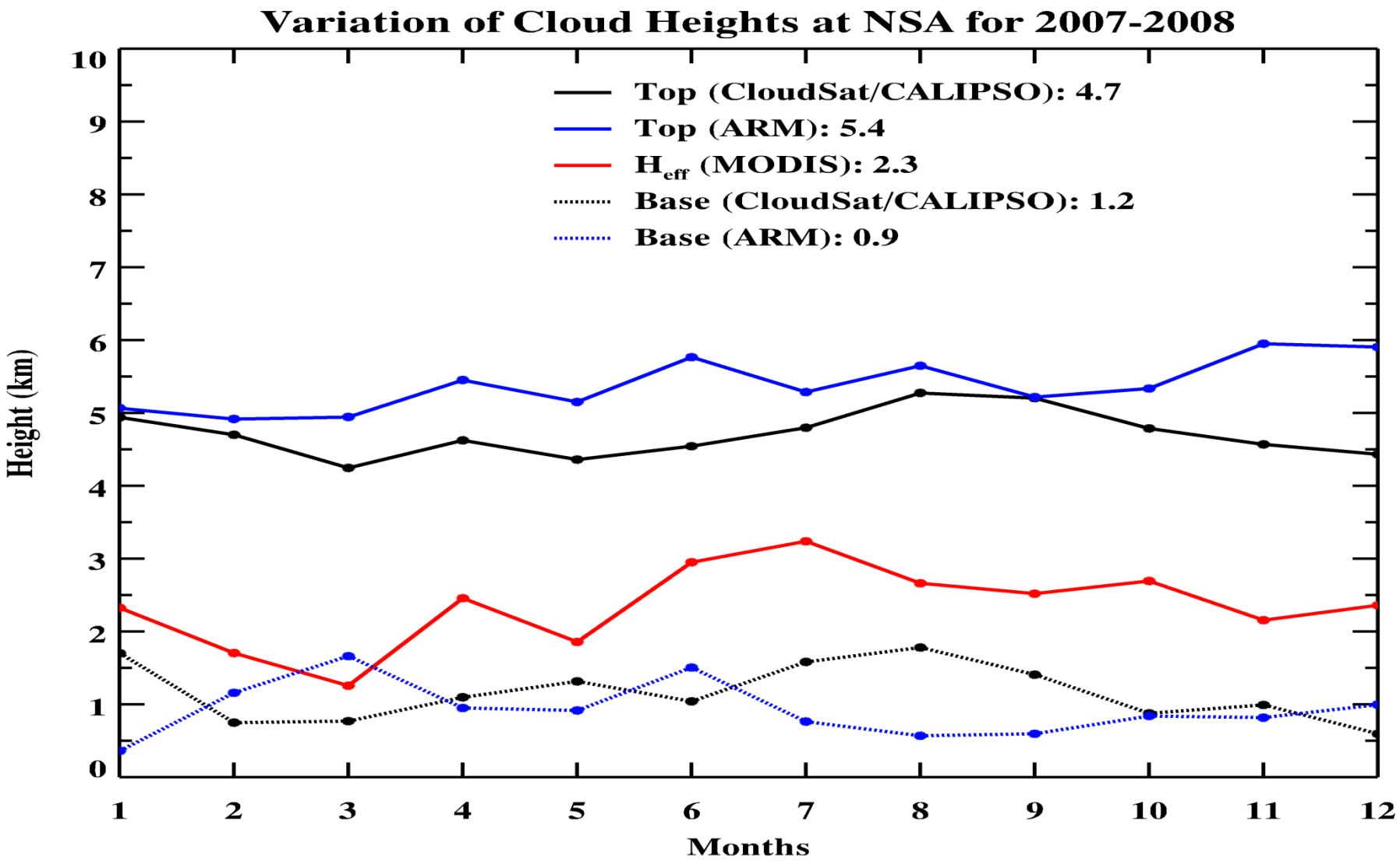
➔Cloud fraction

➔ Cloud-base and -top heights

➔ Daytime cloud microphysical properties from the selected single-layered stratus cases

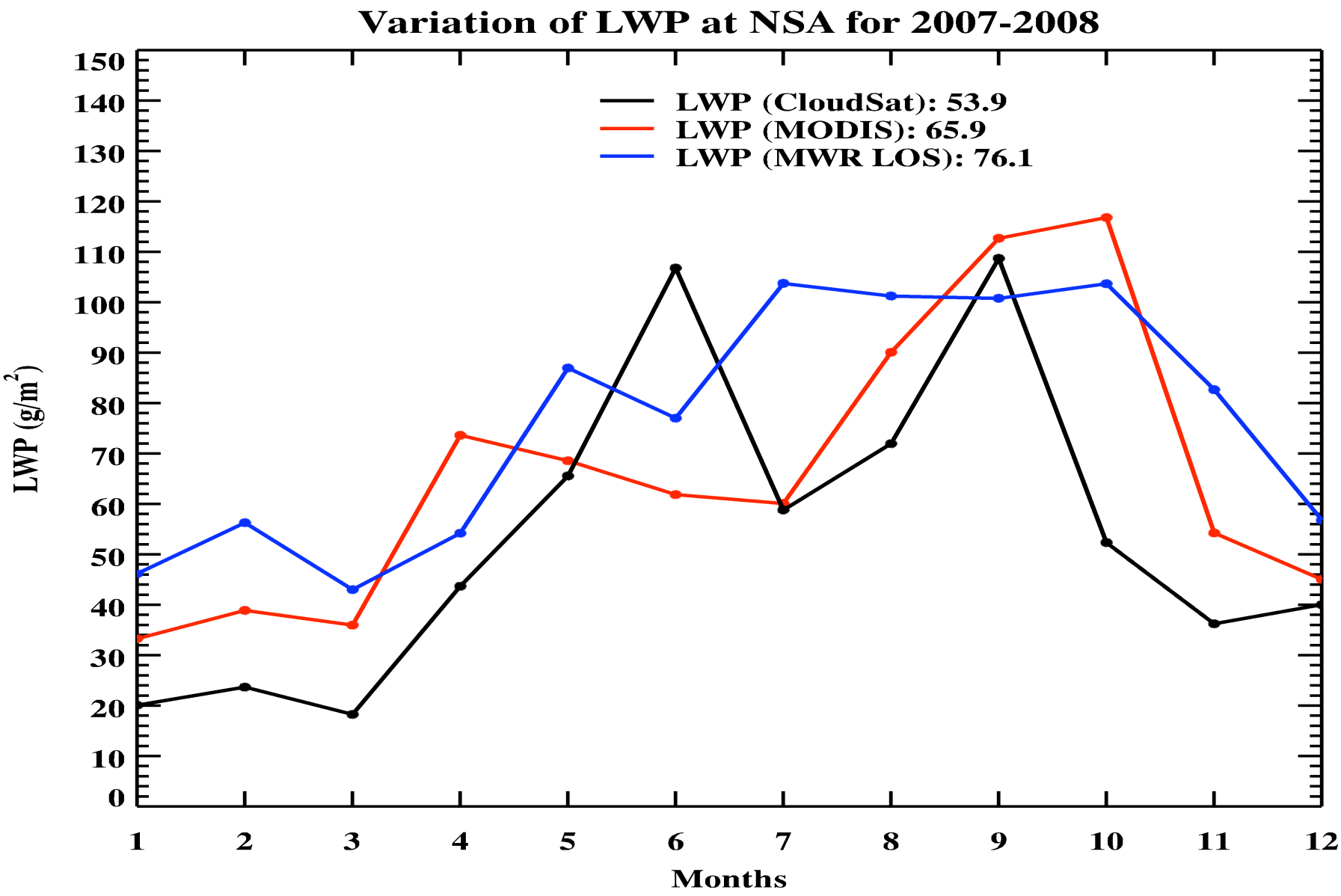


Compared with ARM CF, CloudSat/CALIPSO CF is only 2% lower, while MODIS CF is 7% lower, mostly from Winter months.



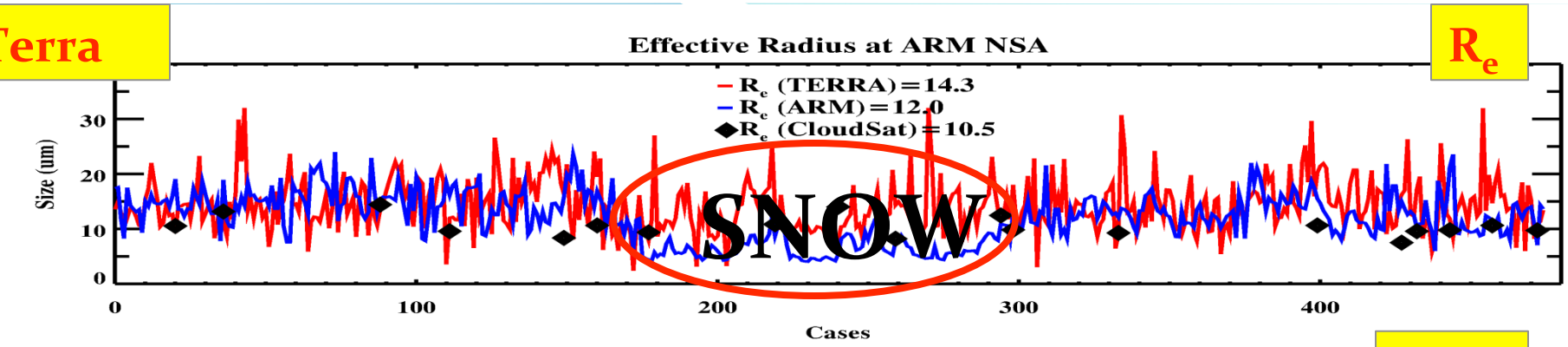
➔CERES-MODIS derived effective cloud heights are near/below cloud center because more ice particles over upper part of clouds (cloud emissivity < 1).

➔The averaged cloud top and base from CloudSat/CALIPSO agree very well with ARM observations (differences are around 300-700 m)

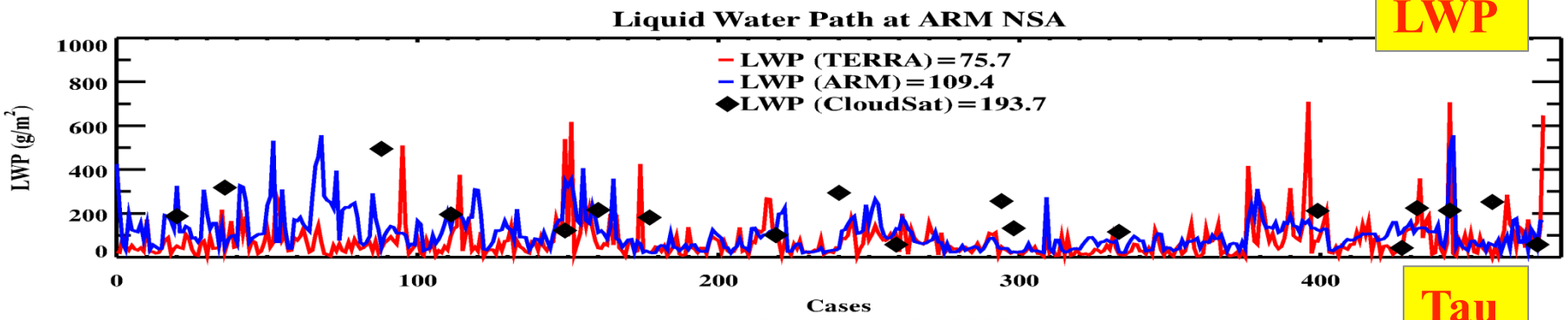


The ARM averaged LWP is 76 gm^{-2}, MODIS is 10 gm^{-2} less. CloudSat LWPs are lower year-round except June and Sept.

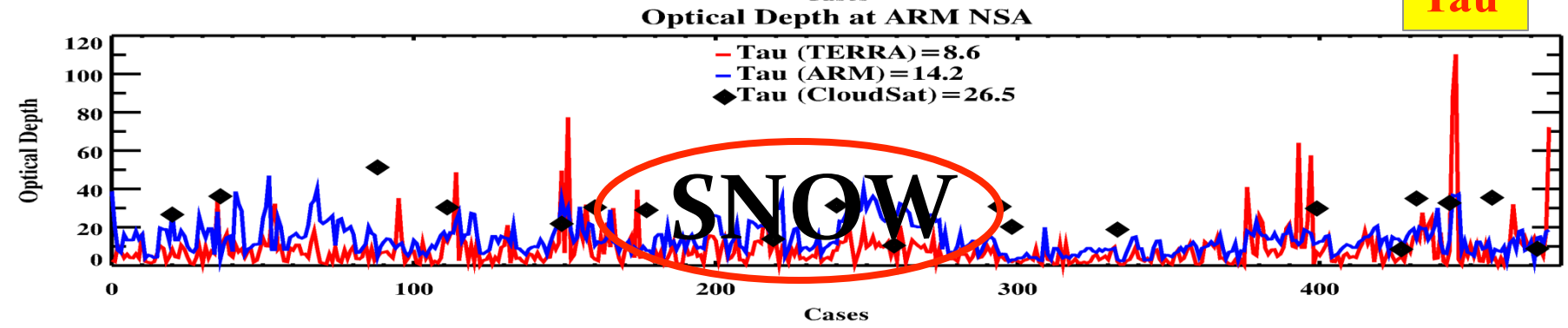
Terra



R_e



LWP

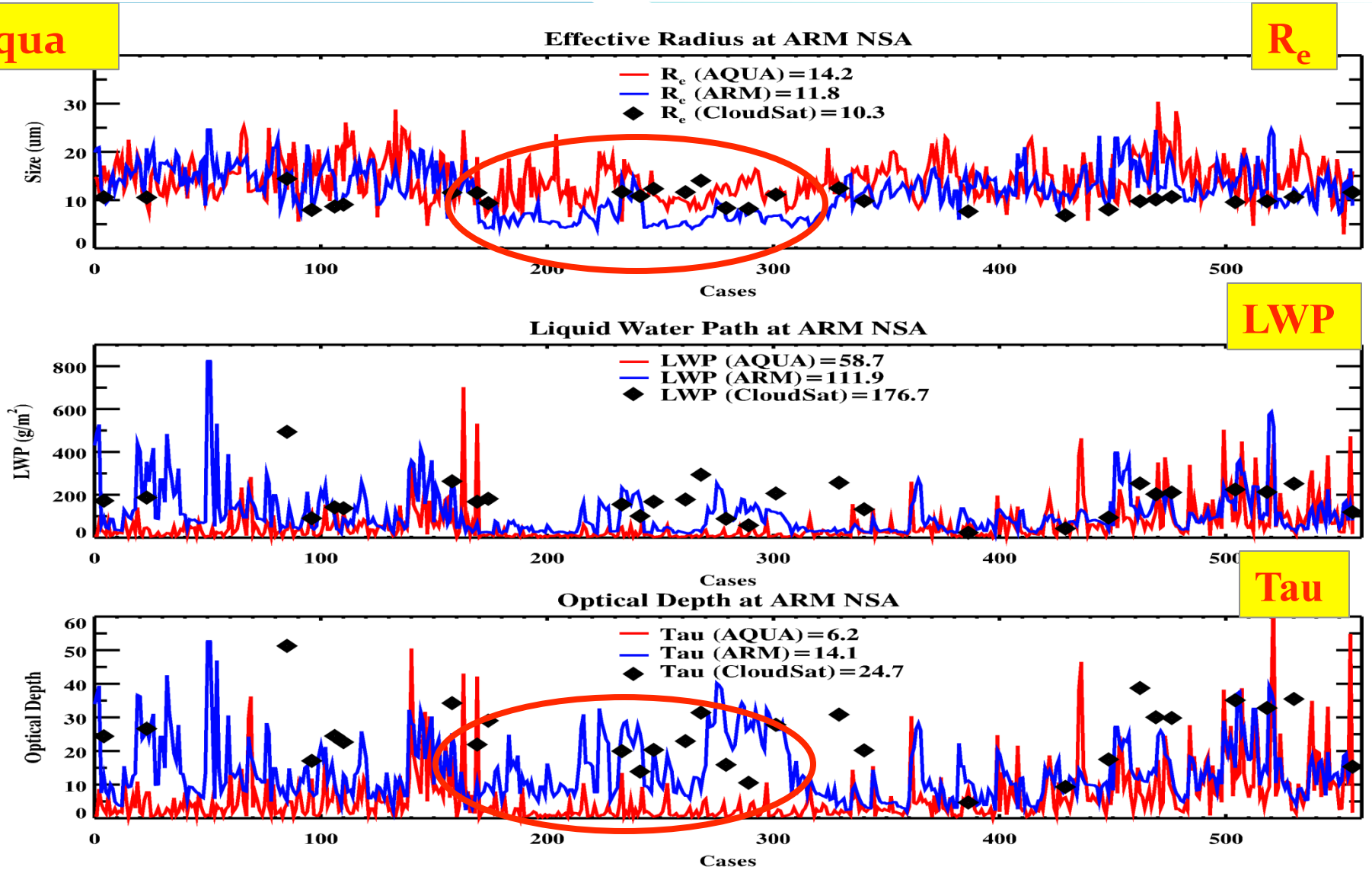


Tau

➔MODIS re is 2.3 μm larger and optical depth is 5.6 less than ARM results.

➔For CloudSat retrievals, its re values are close to ARM, but its optical depth (LWP) are much higher.

Aqua



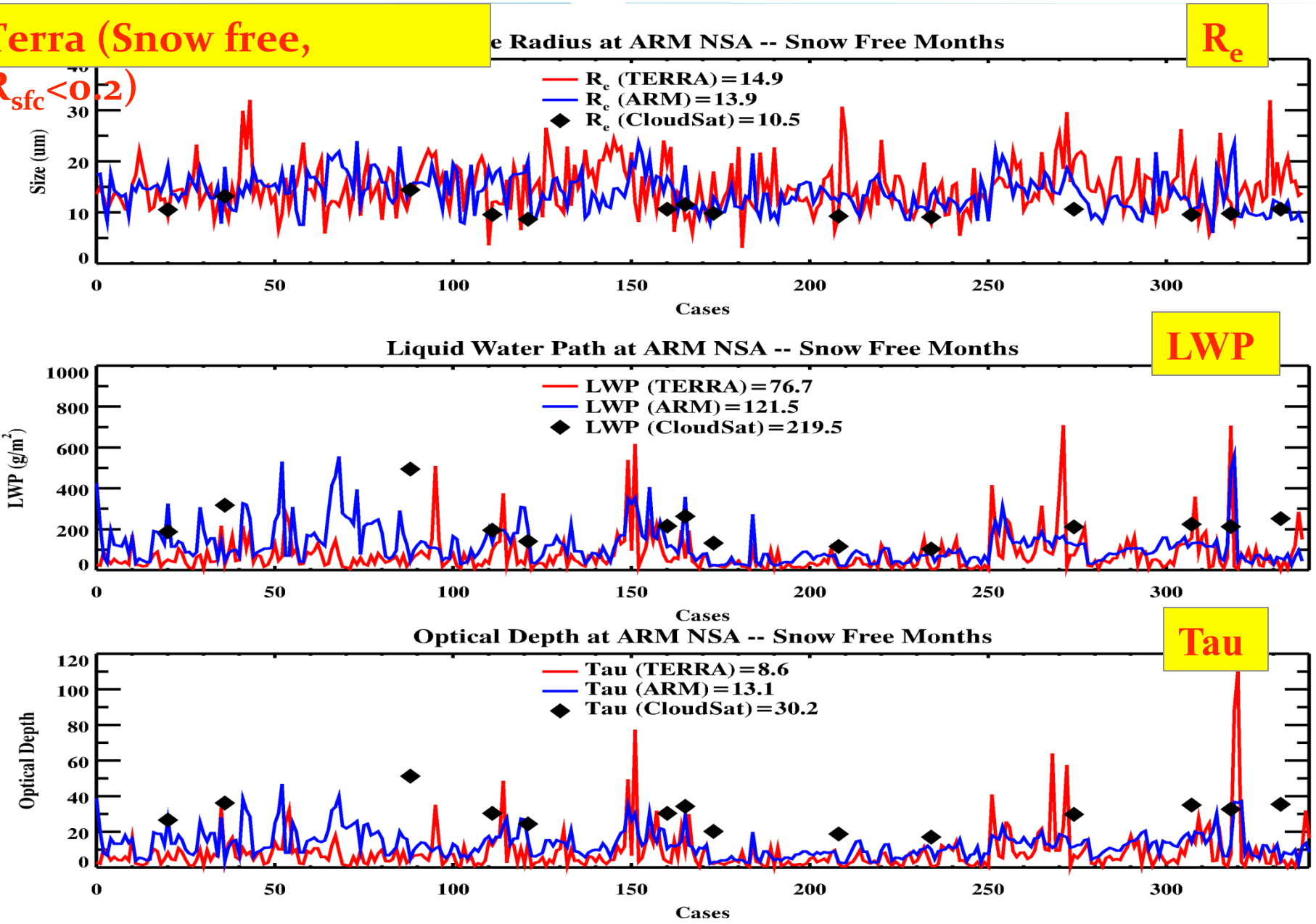
R_e

LWP

Tau

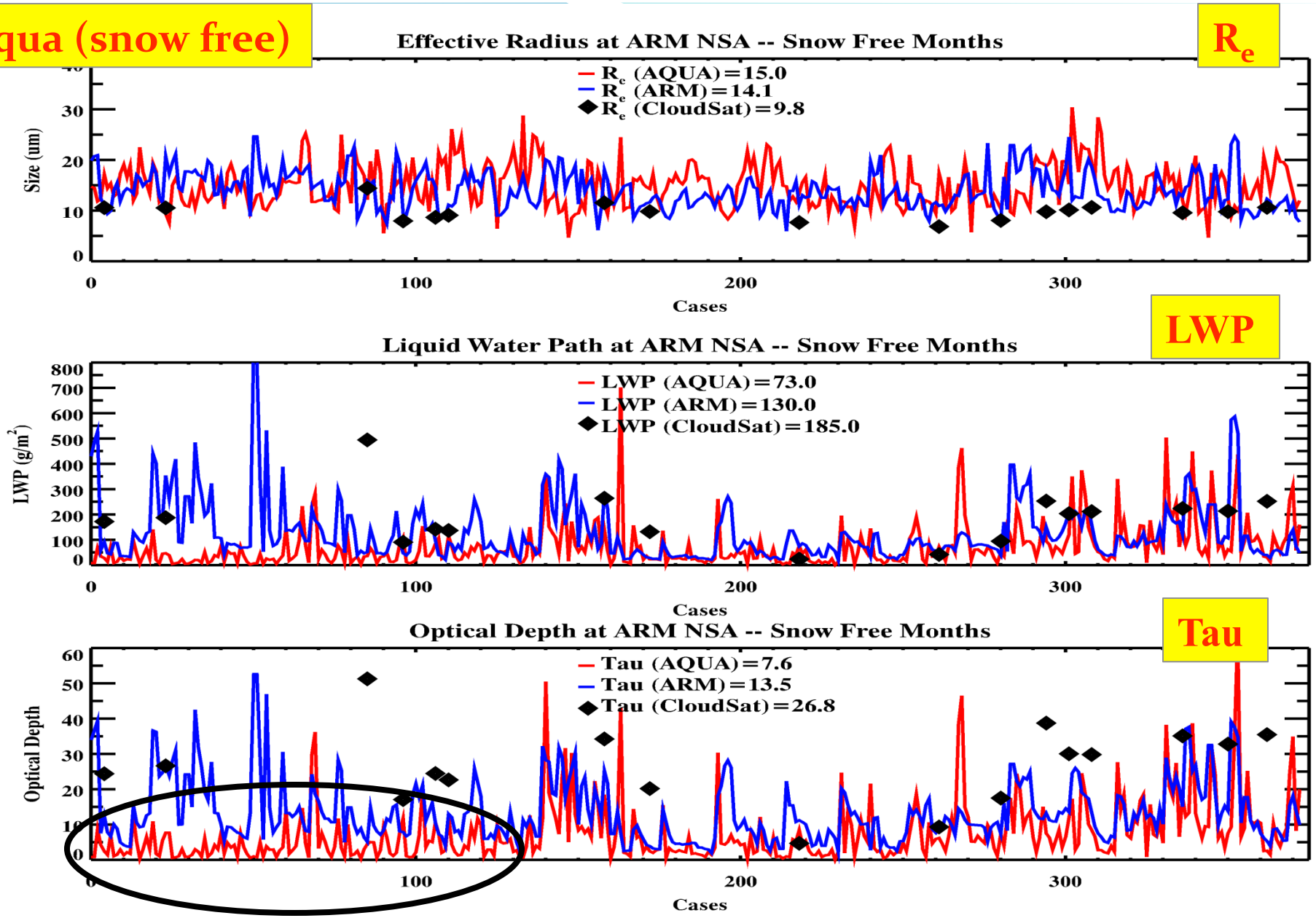
The overall comparison for Aqua is similar to Terra, or slight worse. The largest differences occurred in cases 150 through 320 (Aqua) and cases 150 through 300 (Terra) , which motivated us to break down the cases into those with and without snow cover.

Terra (Snow free, R_{sfc}<0.2)



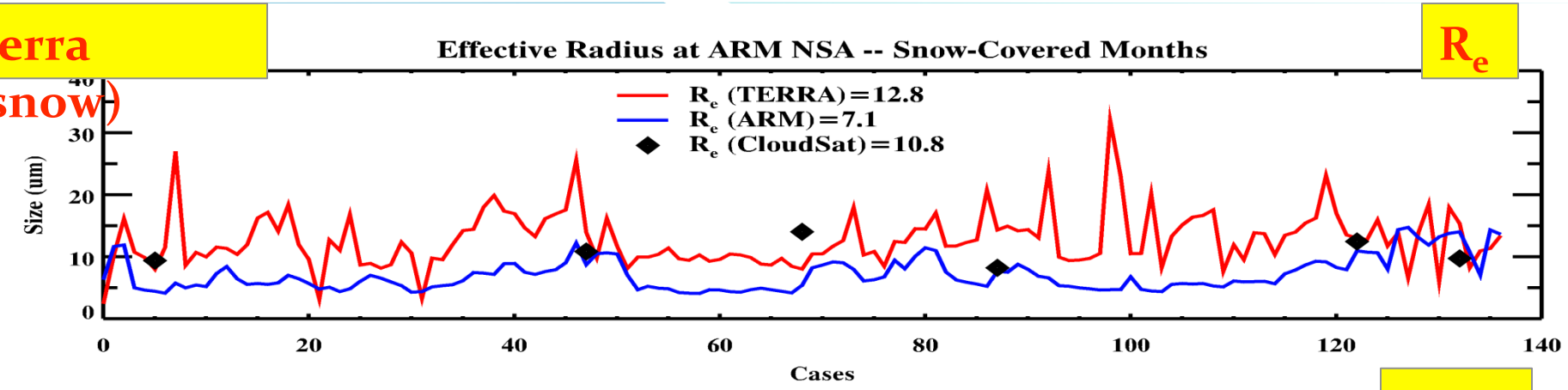
MODIS retrievals agree much better for snow-free surface during summer months.

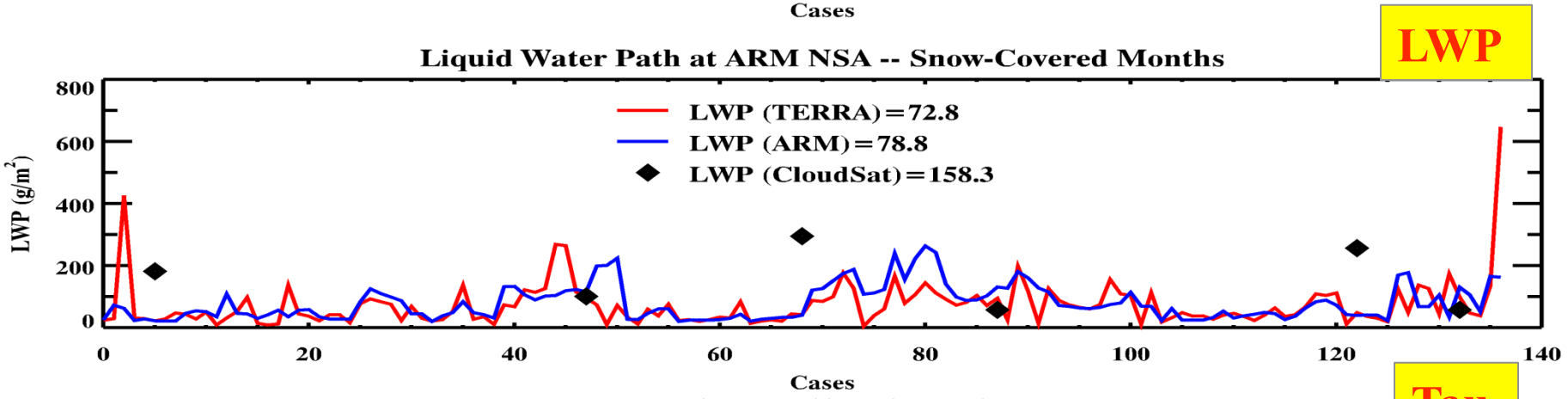
Aqua (snow free)

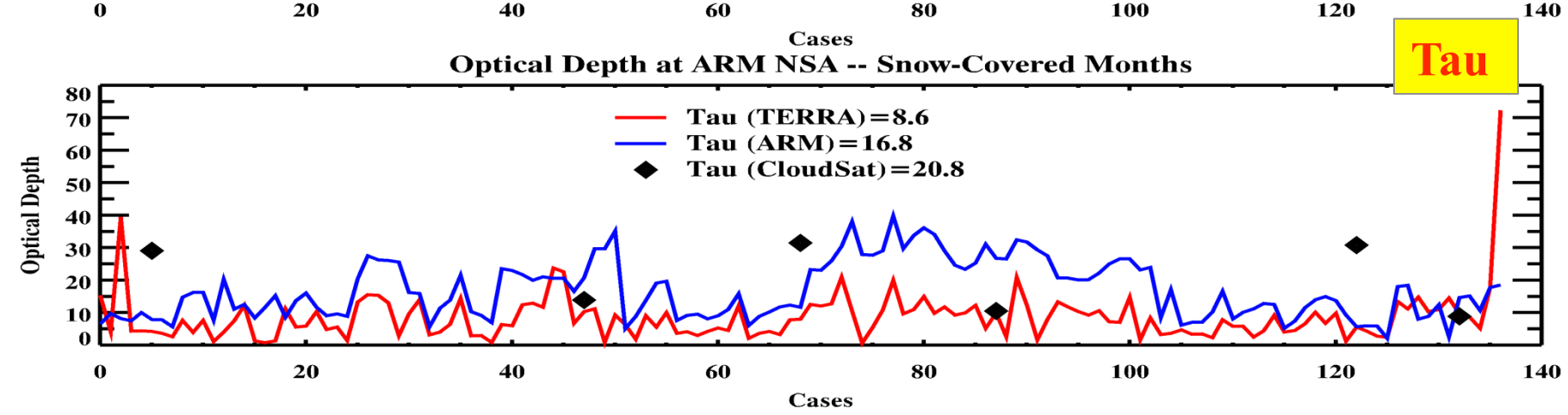


Very similar to its Terra comparison. However, MODIS optical depth values are much lower for cases 1-124➔ a further study.

Terra (snow)

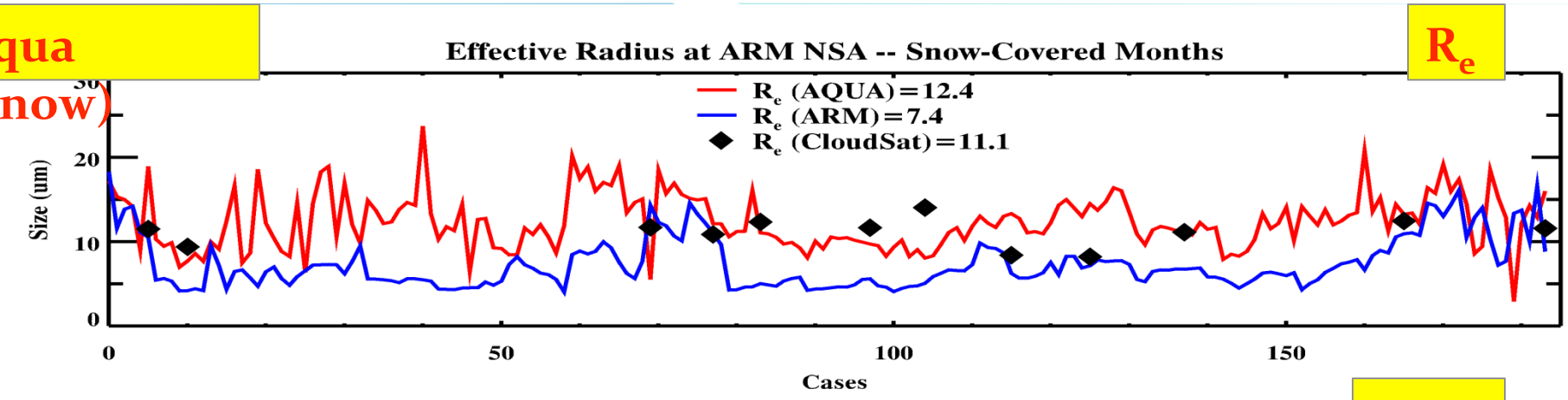


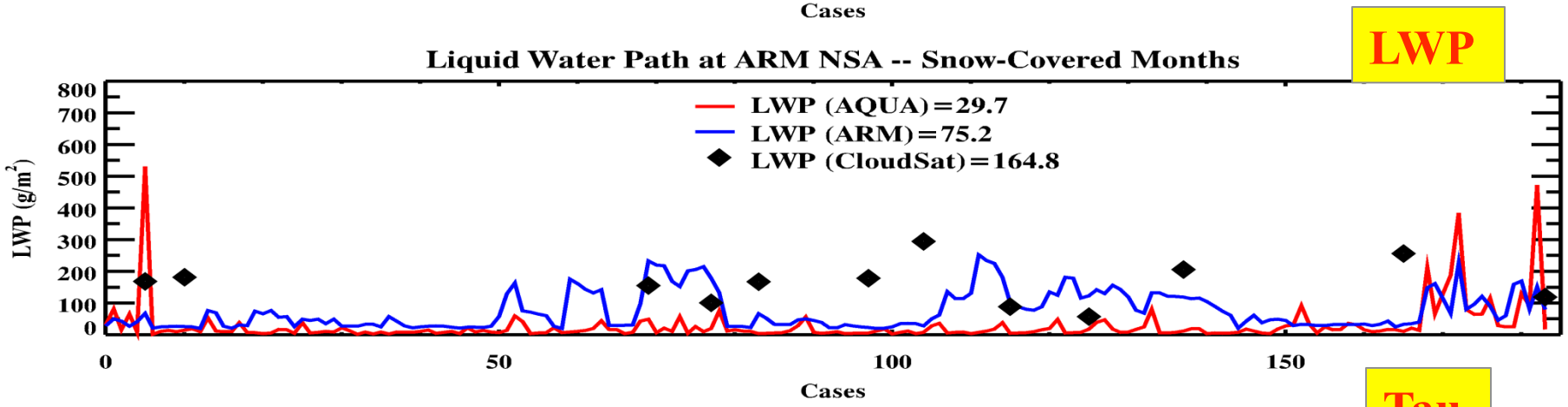


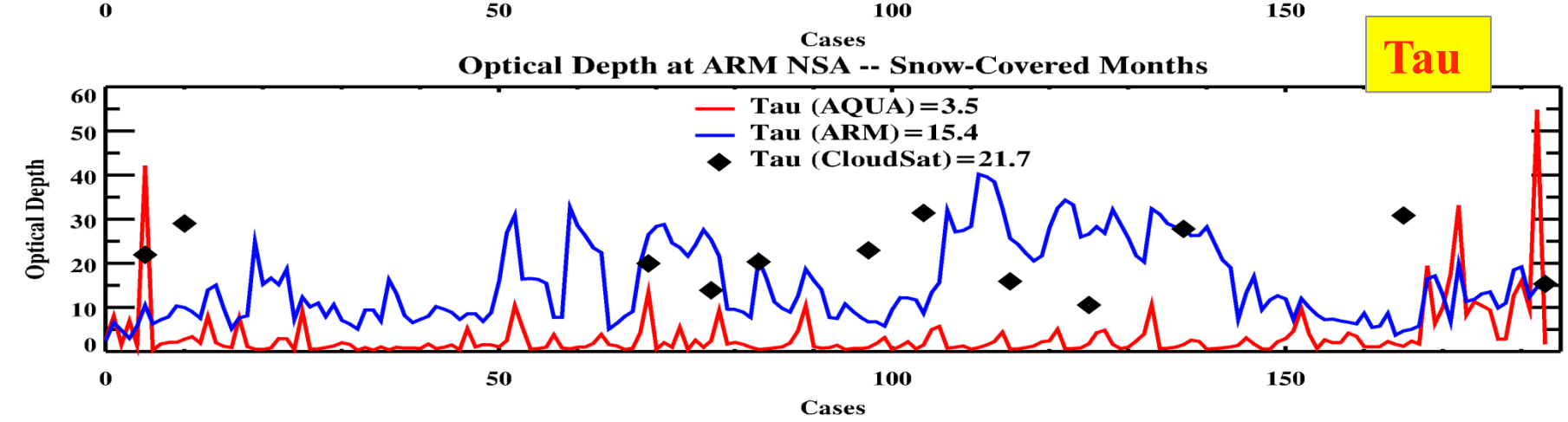


The differences are much larger under snow conditions

Aqua (snow)







Differences are similar to those in the Terra comparison

Conclusions

Snow free (summer)

	re	LWP	Tau
ARM	14.0	125.9	13.3
Terra	14.8	76.7	8.6
Aqua	15.0	73.0	7.6

Snow cover (spring/fall)

	re	LWP	Tau
ARM	7.3	77.0	16.1
Terra	12.8	72.8	8.6
Aqua	12.4	29.7	3.5

1) The ARM retrieved re and LWP during summer are much larger than those in Spring/Fall, same as those in Dong and Mace (2003) study.
2) Both Terra and Aqua results agree with ARM results much better during summer than during spring/fall, so CERES cloud retrieval method needs to be improved over snow surface.
3) Also over snow, Terra and Aqua retrieved re values are almost the same (from 3.7-μm), but optical depth values from Aqua (2.1-μm) are much smaller than those from Terra (1.6-μm).

Conclusions (cont)

2. Macrophysical results at ARM NSA

- **The averaged CFs from ARM, CloudSat and MODIS are 74%, 72%, and 67%, respectively. During Winter months, MODIS CFs are much lower.**
- **MODIS derived effective cloud heights are near/below cloud center because more ice particles exist over upper part of clouds (cloud emissivity < 1). The averaged cloud top and base from CloudSat/CALIPSO agree very well with ARM observations (differences are around 300-700 m).**

3. Cloud fraction over entire Arctic

➔CloudSat/CALIPSO CF=65%, MODIS CF=63%.

➔Although their mean CF difference is only 2%, there are large differences over some regions, possible due to active and passive remote sensing methods to detect clouds over snow/ice covered surfaces.


Thanks for your attention